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Metcalf and Eddy, Inc., Wakefield, MA

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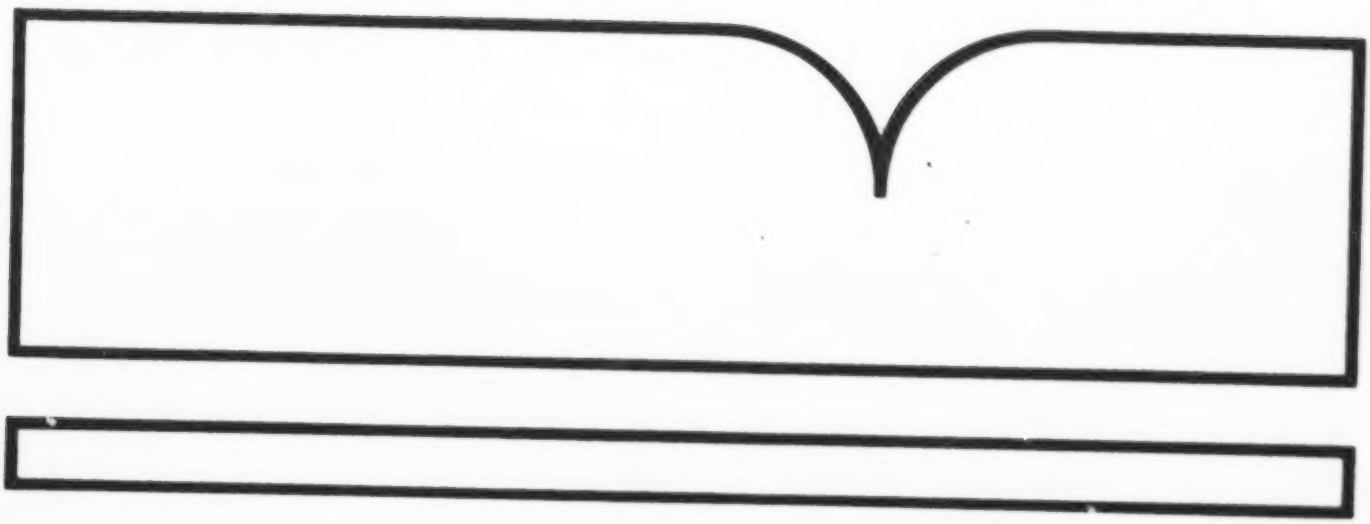

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16. ABSTRACT

Performance problems at publicly-owned treatment works are often attributed to the recycling of sidestreams generated in the wastewater treatment and sludge handling systems. Although the volumes of these sidestreams are generally small compared to plant influent flows, sidestreams can contain significant concentrations of organic and inorganic materials, either in solution or suspended solids form. These recycle loads can be considerably stronger and have characteristics different from the plant influent. Recycle of these sidestreams within the treatment plant without regard to their effects can cause process upsets, violation of discharge limits, release of odors, and increased operation and maintenance costs. The impacts of recycles can be reduced if sidestreams are adequately defined and accommodated in treatment plant design and operation.

This report addresses handling of recycle flows and loads, sources and characteristics of sidestreams, potential adverse impacts of sidestreams on plant performance, design and operation procedures that can reduce sidestream impacts, and use of a mass balance to assess sidestream impacts.

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EPA Design Information Report

The U. S. Environmental Protection Agency has undertaken a program to help municipalities and engineers avoid problems in wastewater treatment facility design. A series of documents will be produced that identify frequently occurring process design problems and describe remedial measures and design approaches used to solve these problems. The intent is not to establish new design practices, but to concisely document improved design procedures that have been developed from field experiences. Readers are encouraged to use the *Journal's* discussion section to contribute additional information or views on these topics.

Sidestreams in wastewater treatment plants

Performance problems at publicly-owned treatment works are often attributed to the recycling of sidestreams generated in the wastewater treatment and sludge handling systems. Although the volumes of these sidestreams are generally small compared to plant influent flows, sidestreams can contain significant concentrations of organic and inorganic materials, either in solution or suspended solids form. These recycle loads can be considerably stronger and have characteristics different from the plant influent. Recycle of these sidestreams within the treatment plant without regard to their effects can cause process upsets, violation of discharge limits, release of odors, and increased operation and maintenance costs. The impacts of recycles can be reduced if sidestreams are adequately defined and accommodated in treatment plant design and operation.

This report addresses handling of recycle flows and loads, sources and characteristics of sidestreams, potential adverse impacts of sidestreams on plant performance, design and operation procedures that can reduce sidestream impacts, and use of a mass balance to assess sidestream impacts.

SIDESTREAMS

Wastewater treatment plant sidestreams originate from either liquid treatment or sludge handling processes, as shown in Table 1.[1,2] Sidestreams result from wastewater filtration and screening; tank and plant washdown; and solids thickening, dewatering, and stabilization. Sidestreams include all of the constituents of the plant influent. However, the quantitative characteristics of these constituents and their distribution among the source processes are different from, and not in direct proportion to, those of the plant influent. These differences depend on the sidestream and include the concentration and form of the constituents as well as their settling, thickening, dewatering, stabilization, and oxidation properties. For example, solids carried in the supernatant from gravity thickening consist primarily of fine, colloidal material rather than dense, more easily settled material found in the plant influent.

The variability of sidestream characteristics is caused by changes in plant influent composition; treatment processes, equipment sizing, and performance; chemical use and points of application; and process operating schedules (continuous or intermittent). In general, the volume or flow of a sidestream depends on the hydraulic loading on the source process or operation; the higher the hydraulic loading, the greater the sidestream flow. Pollutant loads of a sidestream primarily depend on the source process, which defines the composition, and on process performance, which determines the loading. The flow and load of a specific sidestream varies considerably with changes in raw wastewater characteristics, performance of contributing upstream processes, and alterations in operating procedures of the source unit processes.

General data on the composition of sidestreams are presented in Table 1, and more complete data can be found elsewhere.[2,3] Table 2 presents information that helps to explain the range of values in Table 1. Table 2 shows the influence of only one factor,

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Table 1—Sources and characteristics of sidestreams.[1,2]

Source		BOD_5, mg/L	TSS, mg/L
Liquid treatment			
Microscreens	Washwater	100–500	240–1 000
Dual and multimedia filters	Washwater	50–500	100–1 000
Carbon absorption	Washwater	50–400	100–1 000
Tank washdown	Washwater	Negligible	Highly variable
Plant washdown	Washwater	Negligible	Highly variable
Sludge handling			
Thickening			
Gravity thickener	Supernatant	100–1 200	200–2 500
Dissolved air flotation	Subnatant	50–1 200	100–2 500
Centrifuge	Centrate	170–3 000	500–3 000
Dewatering			
Belt filter press	Filtrate	50–500	100–2 000
Centrifuge	Centrate	100–2 000	200–20 000
Recessed plate press	Filtrate	50–250	50–1 000
Vacuum filter	Filtrate	100–1 000	200–4 000
Sludge lagoon	Supernatant	100–200	50–200
Sludge drying bed	Underdrainage liquor	20–500	20–500
Stabilization			
Aerobic digestion	Decant	100–2 000	100–10 000
Anaerobic digestion	Supernatant	100–2 000	100–10 000
Composting (extended aeration, static pile)[1]	Leachate	2 000	500
Incineration	Scrubber water	30–80	600–8 000
Wet air oxidation	Decant liquor	3 000–15 000	100–10 000
Conditioning			
Heat treatment	Decant liquor	1 600–12 000	100–10 000
High-pressure chemical oxidation	Decant liquor	1 000–3 000	100–3 000

upstream processes, on the characteristics of the filtrate produced by vacuum filters. The example is based on engineering practice. Expected characteristics are significantly influenced by contributing upstream processes.

Published data on sidestream characteristics should be used only as a guide and applied with judgement. Mass balance results that assess process performance and capture efficiency, and data from the performance of similar facilities can be used to assess sidestream characteristics for new plants. For existing facilities, problem sidestreams can be sampled and analyzed to determine sidestream characteristics.

IMPACTS OF SIDESTREAMS AND MITIGATION MEASURES

A summary of major sidestream impacts on plant performance and the corresponding mitigation measures is given in Table 3. The severity of these impacts depends on several factors which

Table 2—Example of variation in vacuum filter filtrate characteristics for a 3785-m^3/d (1-mgd) plant.

Processes following primary sedimentation	Sidestream flow, m^3/d (gpd)	Sidestream concentration, mg/L		Sidestream load, kg/d (lb/d)	
		BOD	SS	BOD	SS
Anaerobic digestion + vacuum filter	13.2 (3500)	250	1300	4.5 (10)	18.1 (40)
Activated sludge + gravity thickener + anaerobic digestion + vacuum filter	19.7 (5200)	390	2600	9.1 (20)	49.9 (110)
Activated sludge + DAF + an aerobic digestion + vacuum filter	16.7 (4400)	410	2400	9.1 (20)	40.8 (90)
Activated sludge + DAF + aerobic digestion + vacuum filter	19.7 (5200)	790	2200	13.6 (30)	45.4 (100)
Trickling filter + gravity thickener + anaerobic digestion + vacuum filter	13.2 (3500)	310	1900	4.5 (10)	27.2 (60)
Trickling filter + DAF + anaerobic digestion + vacuum filter	14.4 (3800)	340	2100	4.5 (10)	27.2 (60)
RBC + gravity thickener + anaerobic digestion + vacuum filter	14.0 (3700)	340	2000	4.5 (10)	27.2 (60)
RBC + DAF + aerobic digestion + vacuum filter	14.4 (3800)	350	2100	4.5 (10)	31.8 (70)

Table 3—Major impacts of sidestreams and potential mitigation measures.[3-4]

Sidestream source*	Character of impact	Process impacted	Mitigation measure
Filter washwater	Hydraulic surges	Sedimentation	Backwash storage to equalize flows
		Biological	Reduce trickling filter recycle rate
	Effluent degradation by colloidal SS	Sedimentation	Flocculant aid ahead of settling tank
Sludge thickening	Effluent degradation by colloidal SS	Sedimentation	Flocculant aid ahead of settling tank
			Separately thicken primary and biological sludges
			Optimize gravity thickener dilution water
	Floating sludge	Sedimentation	Minimize gravity thickener sludge detention time
			Continuous, uniform sludge removal
	Odor release and septicity	Recycle point	Reduce gravity thickener sludge detention time
			Return flows ahead of aerated grit chamber
		Biological	Return odorous flows to aeration tank
			Continuous uniform sludge removal
	SS build-up	Sedimentation	Continuous uniform sludge removal
			Include recycle flows in settling tank area computation
		Biological	Adequate sludge pumping rate
Sludge dewatering	Effluent degradation by colloidal SS	Sedimentation	Optimize solids captured at dewatering unit by improved sludge conditioning and improved unit operation/maintenance
			Flocculant aid ahead of settling tank
			Return centrate/filtrate to thickener
	SS build-up	Sedimentation	Increase dewatering unit operation time
		Biological	Include recycle flows in settling tank area computation
			Continuous, uniform sludge removal
			Reduce trickling filters recycle rate
Sludge stabilization	Effluent degradation by BOD	Biological	Regular supernatant/decant removal
			Minimize temperature and pressure in heat treatment/wet air oxidation process
			Separate treatment of supernatant/decant
			Increase RBC rotation speed
			Aeration in channels ahead of RBC
			Increase aeration rate in activated sludge system
			Increase MLVSS in activated sludge system
	Effluent degradation by nutrients	Biological	Regular digester supernatant/decant removal
			Thicken sludge before stabilization
			Separate treatment of supernatant/decant
Sludge conditioning	Odor release and septicity	Recycle point	Return to aeration tank
			Return supernatant/decant ahead of aerated grit chamber or aerate before return to mainstream process
			Reduce solids detention time in heat treatment decant tank
			Regular supernatant/decant removal
		Sedimentation	Continuous uniform sludge removal

* See Table 1 for characteristics.

include the flow train in a plant, the specific design data and operating criteria of a plant, and the percent of plant design capacity in service. In some cases, separate treatment of sidestreams may be required to prevent or mitigate adverse impacts on mainstream processes.

The process flow train in a treatment plant defines the number, types, and potential adverse impacts of sidestreams. For example, trickling filters produce a humus-like sludge that is more easily thickened and dewatered than activated sludge, which generally results in a cleaner, lower volume, recycle stream than is found in activated sludge plants.

Design and operating criteria for a plant, including influent characteristics, effluent quality objectives, and operational constraints, determine plant processes, equipment sizing, and required process performance. These in turn establish the sidestream characteristics and the best points of recycle. Sidestream volumes should be considered when sizing equipment and when using a mass balance to estimate process performance. If the volumes are not considered, the processes and equipment may be improperly sized and may not meet performance standards.

The percent of plant capacity in service directly affects the severity of impacts. A plant that does not operate near its design capacity may exhibit few effects from plant recycles because adequate treatment may result from the availability of the plant reserve capacity. However, the adverse impacts of sidestreams at the same plant when it is at or near design capacity could be severe. Although the severity of the impacts of underestimated recycles will vary from plant to plant, costs for chemicals, energy, operation, and maintenance will increase because the original plant design will fail to incorporate the capacity, processes, and

operational flexibility to handle the unanticipated recycle flows and loads.

Mitigation measures include design and operations procedures that decrease sidestream flows and loadings, lessen their effects, or provide adequate process sizing to handle their loads. The procedures in Table 3 outline major actions that may be taken. Further reports on a specific procedure can be found elsewhere.[2-4] Selection and implementation of a particular action will depend on the flexibility in plant design, mainstream operational constraints, and effluent discharge requirements.

For example a heavy organic loading associated with recycles from anaerobic digestion in a facility that includes a mainstream activated sludge process could be handled by direct recycle to the aeration tanks and by increased mixed liquor suspended solids concentrations and aeration rates. However, if the return sludge and aeration systems are not sized to allow such modifications, alternative methods of handling the digester recycle must be considered. If the digester operation has already been optimized, such measures might include separate treatment of the supernatant, or rehabilitation of the activated sludge system to accommodate the load.

Separate treatment of sidestreams should be the last mitigation measure taken to minimize sidestream impacts in an existing plant. Generally, separate treatment is used for problem sidestreams, plants at capacity with recycle problems, or for large plants because it is not cost-effective to provide a treatment system for a low-volume, high-load flow. Problem sidestreams such as heat treatment liquor, wet-air oxidation liquor, and digester and sludge lagoon supernatant, can contribute an additional pollutant load on a plant because of high biological oxygen demand (BOD), chemical oxygen demand (COD), ammonia, organic nitrogen, suspended solids, and phosphorus concentrations. Separate biological and chemical treatment may be required to reduce these loads and to control the release of odors. Such treatment can include trickling filters, aerobic digestion, anaerobic or aerobic fixed-film processes, chemical coagulation, activated carbon, and ozonation. These treatment processes and their effects on sidestream constituents are discussed more completely, elsewhere.[3,5]

MASS BALANCE

The mass balance is a tool used to predict characteristics of each stream in a treatment plant. The mass balance enables plant designers and operators to predict loading conditions on each mainstream and solids handling unit within a facility, and to identify potential trouble spots caused by recycle streams.

The development of a mass balance is described elsewhere.[3,5,6] It is normally formulated using published process efficiency data, but accuracy can be significantly improved if actual field or treatability data are available. Mass balances should be developed for average operating conditions and the results adjusted to assess conditions that vary from the average, that is, peaking conditions and daily operating schedules. For new, expanded, or upgraded plants, balances should be performed for both average initial and design conditions with subsequent adjustment for peaks and operating schedules.

A summary of a mass balance for a secondary treatment plant is shown in Figure 1. As shown in the figure, the mass balance readily identifies major characteristics of the main process flow

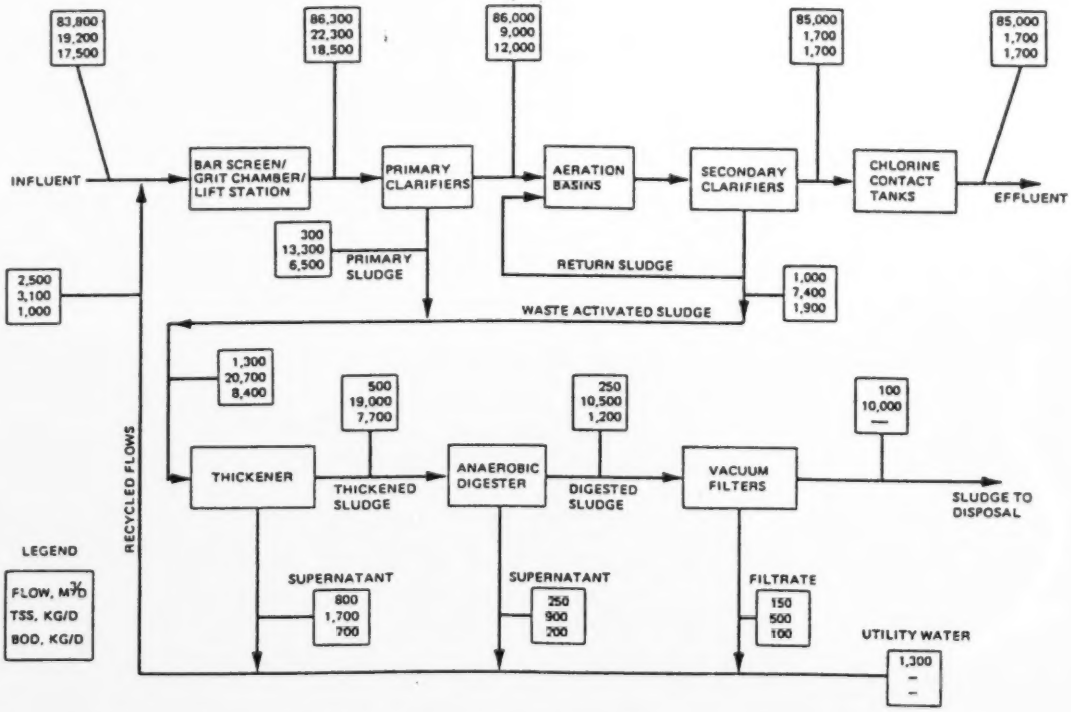

Figure 1—Example of summary data for mass balance for average conditions.

stream, individual sidestreams, and all points of recycle. Incremental loading caused by recycled flows and loads in this figure illustrates the magnitude of the impact that recycle streams may have on a plant. In this example, recycle flows are only 3% of the plant influent flow, but recycle solids loadings are 16% of the plant influent solids. Waste activated sludge production is low because an aeration system with a low growth rate is modeled.

In existing plants, the results of the balance can help to determine whether or not mainstream processes can handle sidestream flows and loads. In new designs, balance results can help determine the extent of added mainstream process capacity that will be needed to handle high-strength recycles.

If the anaerobic digester was removed from the treatment system shown in Figure 1, for example, the plant recycle BOD load would be reduced by approximately 20%, causing a 2% reduction in the organic load on the activated sludge system. This has a minor impact on system sizing and cost. However, if a thermal conditioning system were substituted for the example digestion system, recycle BOD loads could increase 100% and aeration tank loadings could increase by as much as 10%. This increased load would significantly affect aeration system design and cost.

The need for and impacts of treatment of high strength sidestreams can also be assessed for the system in Figure 1. Separate aerobic treatment of the thermal conditioning system recycle might be more cost-effective than an increase in aeration system capacity.

The mass balance is developed using an iterative technique that defines an average loading condition on the processes and operations in a plant. Because it is developed from a number of steady-state operating assumptions, a mass balance represents a "snap-shot" of a treatment plant and cannot be used to model the dynamic conditions associated with peaks. The impacts of start-up, initial operations, and peak loading conditions are not solely defined by the mass balance results. Daily, weekly, and seasonal variations occur that affect the flow and strength of raw wastewater and plant sidestreams. Additionally, process performance does not respond instantly to changes in process influent characteristics. These conditions, however, can be evaluated based on mass balance results that model average initial and design year conditions.

For example, it may be thought that a peaking condition that doubles the BOD load on an activated sludge system will produce an equal increase in waste activated sludge mass. However, the mass of sludge wasted would not necessarily double because other factors such as the quantity of fixed solids contained in the sludge, delayed response of cell growth rate to load increases, and reduced process efficiency under peak loading conditions increases the mass sludge production by a less than proportionate amount. In addition, the concentration of waste sludge may be diminished under peak BOD loading conditions, so that the volume of the waste sludge stream may increase in excess of a factor of two when BOD loads are doubled.

Further assessments that should be made on completion of a mass balance are the impacts of the daily operating schedule and weekend shutdowns on sidestream constituents. A mass balance depicts average conditions, essentially assuming 24-hour operation. If various components of a treatment facility (such as thickening and dewatering) are not operated 24 hours per day, 7-days a week, the volume and mass loading of the sidestreams that they generate must be proportionately adjusted to assess peak loading conditions.

For example, if the vacuum filters shown in Figure 1 are operated on 5 rather than 7 days a week, the digested sludge flow rate will be 7/5 times the value in Figure 1 ($7/5 \times 250$ m^3/d $= 350$ m^3/d). This is a 40% increase in sludge flow rate. It would also cause a 40% increase in the sludge disposal rate. In this particular example, the filtrate BOD load would be increased by 40%, or 40 kg/d, and ultimately cause a 4% increase (40/1000) in plant recycle BOD loads.

If dewatering processes were operated 8 hours a day, 5 days a week, the filtrate flows and loads would be three times greater than those calculated for 5-day a week operation, and would be 4.2 times those calculated for average conditions. However, this imposes only a 2.5% increase in daily peak BOD loads on the aeration system. This peak would be applied to the aeration system in conjunction with other peak conditions. The impact of this load in the aeration system would be buffered by other peaking conditions, the slow response of the activated sludge system to peaks, and the degree of mixing and hydraulic retention time of the activated sludge system.

SUMMARY

Sidestreams are an integral part of the flows and loads in a wastewater treatment plant. Although characteristics and properties of sidestreams may differ from those of the plant influent, adequate consideration of these characteristics in plant design protocol should minimize adverse impacts on treatment plant operation and performance. The following points should be considered to minimize sidestream impacts on mainstream and solids treatment processes:

- Available information on sidestream characteristics may be used as a guide in approximating sidestream flows and loadings. However, each design case should generate and use more reliable sidestream data from plants with similar unit processes and operating conditions.
- Adverse sidestream impacts in new plants can be minimized through development of mass balances during design that incorporate recycle flows and loads, provide for alternate recycle points, and consider separate treatment for problem sidestreams.
- Adverse impacts in existing plants may be mitigated by changing the point of recycle, timing, and return rate; implementation of other operational procedures; and separate treatment for problem sidestreams.
- During the planning and design of a wastewater treatment plant, sidestream flows and loads should be characterized and mass balances developed to describe anticipated requirements for conditions from initial plant start-up through design-year operation. Process design data, equipment sizing, and points of recycle should be established based on the results of the balances with provisions for peak loads and equipment flexibility.

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